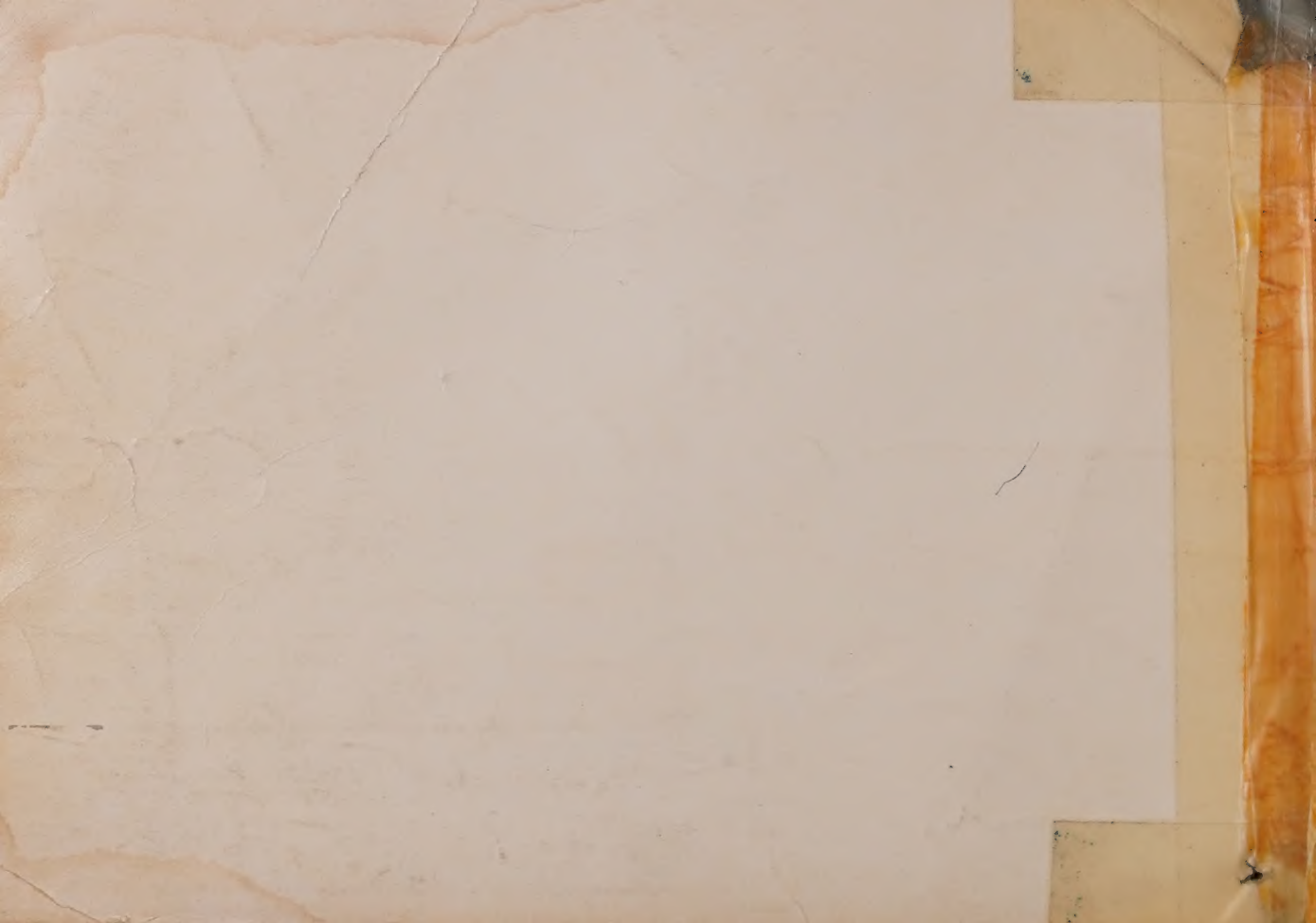


B224

UNIVERSAL BRIDGE

OPERATING INSTRUCTIONS

WAYNE KERR



OPERATING INSTRUCTIONS

for

UNIVERSAL BRIDGE B224

*The Reference Number of
this Publication is TP 43*

THE WAYNE KERR COMPANY LIMITED

ROEBUCK ROAD CHESSINGTON SURREY ENGLAND

CONTENTS

	Page		Page
INTRODUCTION	5	Accuracy of Low Impedance Measure-	
SPECIFICATION	6	ments	24
CONTROLS	10	PARALLEL TO SERIES CONVERSIONS	24
OPERATION	12	EXTERNAL STANDARDS	25
Preliminary	12	General	25
Switching On	12	Comparator—Ranges 4-10	26
Measurement Cables	13	Increased Discrimination—Ranges 4-10	26
Trimming (Normal Measurements—Ranges		Interpretation of Results	28
4-10)	13	Extension of Trim	29
Two Terminal Measurements—Ranges 4-10	14	EXTERNAL SOURCE AND DETECTOR	29
Normal Measurements	14	General	29
Interpretation of Results	16	Source	29
Three Terminal Measurements — Ranges		Detector	30
4-10	17	Operation	32
In-situ Measurements	17	Interpretation of Results	34
Network and Attenuator Characteristics	19	Accuracy	34
Measurement of Screened Components	20	Range Limitations	35
Measurement of Three Terminal Capacitors	20	MEASUREMENT CONDITIONS	36
Four Terminal Measurements—Ranges 1-3	21	LEAD CORRECTIONS	36
General	21	BRIDGE MEASUREMENT	
Trimming (Low Z)	21	TECHNIQUES	39
Resistance Measurement (Low Z)	22	Introduction	39
Inductance Measurement (Low Z)	22	Measurements on Non-Linear Resistive	
Capacitance Measurement (Low Z)	24	Elements	40

Ceramic Capacitors—Ranges 4-10	40
Electrolytic Capacitors—Ranges 1-3	40
Loss Angle	41
Iron-Cored Inductors	41
Inductors Carrying D.C.	42
Temperature Coefficients	43
Measurements on Transformers	43
Turns Ratios	43
Effectiveness of Transformer Screens	43

ILLUSTRATIONS

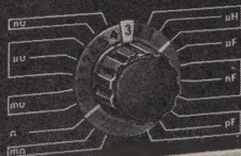
Frontispiece	4
Fig. 1 Normal Measurement Connections	14
Fig. 2 Three Terminal Network	17
Fig. 3 Three Terminal Measurements	17
Fig. 4 In-situ Measurements	18
Fig. 5 Shunting Effects	18
Fig. 6 Network and Attenuator Characteristics	19
Fig. 7 Three-terminal Capacitor	20
Fig. 8 Low Impedance Measurement Connections	21
Fig. 9 Polarising Ceramic Capacitors—Ranges 4-10	40

Fig. 10 Polarising Electrolytic Capacitors—Ranges 1-3 (Table 5)	41
Fig. 11 Inductors Carrying D.C.	42
Fig. 12 Transformer Screens	44
Graph 1 Resistance Correction Ranges 1-3	23
Graph 2 Maximum drive at External Source Socket plotted against frequency (Typical)	29
Graph 3 Input Impedance at External Source Socket (Typical)	30
Graph 4 Bridge Sensitivity using Internal Detector when fed with 2V r.m.s. at External Source Socket (Typical)	31
Graph 5 Typical % Unbalance for 5mV r.m.s. at External Detector Socket when B224 is fed with Maximum Input Volts	32
Table 1 Internal R and L for each Range (Typical)	19
Table 2 External Standards	27
Table 3 Range Limitations with Frequency (Ranges 4-10)	35
Table 4 Co=Value of Cx at 1592Hz for Circuit of Fig. 10	41
Table 5 Maximum Permissible Current through Bridge	43

WAYNE KERR

Universal Bridge B224

Range

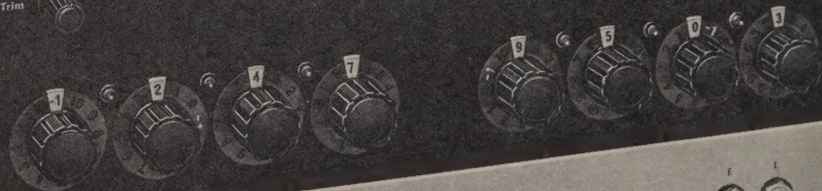


C Term

G Term

Trim

Trim



Off
On
Boost
Charge



0.1 1 -1

Multiplier

Link
Neutrals

Unknown

0.1 1 -1

Multiplier

External Standards



INTRODUCTION

The B224 is a 10 range transformer ratio arm bridge, for the measurement of admittance or impedance, at audio frequencies. On seven of these ranges the accuracy is $\pm 0.1\%$ or better, while on the remaining three (low impedance) ranges, the measurement error does not exceed $\pm 0.3\%$.

Eight Decades—four for capacitance and four for conductance—are operated in succession to obtain a balance, each Decade being provided with a numbered readout. Decimal points are indicated by small signal lamps mounted between the Decade Control knobs, the appropriate lamp being illuminated automatically by operation of the RANGE switch.

Although the instrument standards are of capacitance and conductance, resistance and inductance can also be measured, reciprocal tables being provided at the end of this manual. To simplify the derivation of those values which are frequency dependent, the internal oscillator is adjusted to 1592Hz (at which frequency $\omega = 10^4$).

The instrument has provision for operation with an external source and detector. An external source is necessary if operation is required at any frequency other than that provided by the internal source, though the internal detector may be used over the frequency range 200Hz to 50kHz. The latter facility can prove valuable when operating from battery power on a remote site.

Sockets are provided for the connection of EXTERNAL STANDARDS, and full instructions are given for their use in various types of measurement.

The instrument may be used with a 50 or 60Hz a.c. supply in the voltage ranges 100–125V or 200–250V, or from the internal rechargeable battery. When operated from an a.c. supply, the battery is recharged automatically. A BOOST CHARGE facility is also incorporated. It is important to note that when operating from battery power only, the decimal point indicator lamps are not illuminated.

SPECIFICATION

MEASUREMENT RANGES

Overall

100aF (0.0001pF)—5F

1pΩ—50kΩ

1nH—5MH

1μΩ—500GΩ

For 0.1% Accuracy

100fF (0.1pF)—10μF

1nΩ—100mΩ

1mH—10kH

10Ω—1GΩ

The above coverage is obtained as follows:

(a) DIRECT PARALLEL READOUT

× 1G*			RANGE	× 1C*		
1st div.	Min. for 0.1%	Max. (0.1%)		1st div.	Min. for 0.1%	Max. (0.1%)
10μΩ	10mΩ	100mΩ	4	1nF	1μF	10μF
1μΩ	1mΩ	10mΩ	5	100pF	100nF	1000nF
100nΩ	100μΩ	1000μΩ	6	10pF	10nF	100nF
10nΩ	10μΩ	100μΩ	7	1pF	1nF	10nF
1nΩ	1μΩ	10μΩ	8	100fF	100pF	1000pF
100pΩ	100nΩ	1000nΩ	9	10fF	10pF	100pF
10pΩ	10nΩ	100nΩ	10	1fF	1pF	10pF

* All figures become one-tenth of values quoted with the appropriate 0.1 MULTIPLIER button(s) depressed.

(b) DIRECT SERIES READOUT (in equivalent SERIES components)

R *			RANGE	L *		
1st div.	Min. for 0.3%	Max. (0.3%)		1st div.	Min. for 0.3%	Max. (0.3%)
$10\mu\Omega$	$10m\Omega$	$100m\Omega$	1	$1nH$	$1\mu H$	$10\mu H$
$100\mu\Omega$	$100m\Omega$	1Ω	2	$10nH$	$10\mu H$	$100\mu H$
$1m\Omega$	1Ω	10Ω	3	$100nH$	$100\mu H$	$1mH$

Note : 0.3% accuracy applies after correction for systematic error.

(c) DERIVED PARALLEL VALUES (using reciprocal tables)

R†			RANGE	L ($\omega = 10^4$)		
Min. (0.1%)	Max. for 0.1%	1st div.		Min. (0.1%)	Max. for 0.1%	1st div.
10Ω	100Ω	$100k\Omega$	4	$1mH$	$10mH$	$10H$
100Ω	$1k\Omega$	$1M\Omega$	5	$10mH$	$100mH$	$100H$
$1k\Omega$	$10k\Omega$	$10M\Omega$	6	$100mH$	$1H$	$1kH$
$10k\Omega$	$100k\Omega$	$100M\Omega$	7	$1H$	$10H$	$10kH$
$100k\Omega$	$1M\Omega$	$1G\Omega$	8	$10H$	$100H$	$100kH$
$1M\Omega$	$10M\Omega$	$10G\Omega$	9	$100H$	$1kH$	$1MH$
$10M\Omega$	$100M\Omega$	$100G\Omega$	10	$1kH$	$10kH$	$10MH$

Note : Parallel L ranges are frequency dependent ($L = 1/\omega^2 C$).

* All figures become one-tenth of values quoted with the appropriate 0.1 MULTIPLIER button(s) depressed.

† All figures become ten times the values quoted with the 0.1 G MULTIPLIER button depressed.

(d) DERIVED SERIES VALUES (using reciprocal tables)

RANGE	Min. (0.3%)	Max. for 0.3%	1st div.
1	1mF	10mF	10F
2	100 μ F	1mF	1F
3	10 μ F	100 μ F	100mF

Note: 0.3% accuracy applies after correction for systematic error.
Series C ranges are frequency dependent ($C = 1/\omega^2 L$).

ACCURACY

Figures quoted above in (a) and (c) ($\pm 0.1\%$) apply from 200Hz to 10kHz, subject to corrections being applied for lead impedances (see lead corrections on page 36). Typical figures for higher frequencies are $\pm 0.25\%$ at 20kHz and $\pm 2\%$ at 50kHz. With frequency-dependent values the source frequency must be known to $\pm 0.05\%$ for the specified accuracy to be realised. Without a check on the internal oscillator frequency, L measurements in table (c) and C measurements in table (d) will be accurate to $\pm 2\%$. For tables (b) and (d), the accuracy ($\pm 0.3\%$) applies from 200Hz to 10kHz. Typical figures for higher frequencies are $\pm 0.5\%$ at 20kHz and $\pm 2.5\%$ at 50kHz.

Frequency

Internal source/detector 1592Hz $\pm 1\%$ ($\omega = 10^4$)
External source/detector 200Hz—50kHz

Comparator

Bridge gives direct measurement of difference between Unknown and External Standard(s) of values 100pF—100nF and 1 $\mu\Omega$ —1m Ω (1k Ω —1M Ω)

Ambient Temperature Range

0—40°C

Power Supply	100—125V/200—250V, 50—60Hz
Dimensions	Width 482 mm (19 in.) Height 311 mm (12.25 in.) Depth 152 mm (6 in.)
Weight	Approx. 9kg. (19.5 lb.)

ANCILLARY ITEMS

BNC connectors for external source/detector	Greenpar GE37570C (2 off)
D.V.M. and Battery Plugs	Belling Lee L378/A/4/Red (3off) Belling Lee L378/A/4/Black (3off)
Measurement leads (complete) (BML12)	D10065A (2 off)
Low Capacity Clip leads (LCC3)	D10642B (2 off) —
Power lead (complete)	D10879 (1 off)
Reciprocal Tables	D12461 (1 off)
Instrument stand	D12466 (1 off)
*Power input connector	Bulgin P430
*Measurement connectors (E & I)	Greenpar GE37570C (2 off)†

* Supplied as optional extra.

† Same as supplied for external source/detector.

CONTROLS

RANGE Switch

This ten position switch provides the necessary multiplying factor for the Decade Controls and selects the appropriate decimal point signal lamp.

Decade Controls

Eight Decade Controls are provided, in two groups. Four for G term, and four for C term. The three left-hand controls in each group are twelve position switches: the right-hand one in each group is a potentiometer. The Decade Controls are engraved -1 to 10, although on the three right-hand controls in each group, the 10 is replaced with the symbol $\oplus$. The -1 positions provide overlap, which is useful in dealing with awkward values. The right-hand potentiometer controls enable a precise value to be set on the scales.

The Decade Controls select a combination of standards and transformer taps.

C and G MULTIPLIER Buttons

These two groups of push buttons enable the operator to change the sign and magnitude of the voltage applied to the standards. The 1 buttons enable positive values of C and G to be measured,

while the -1 buttons enable negative values of C (positive values of L) and negative values of G to be measured. The 0.1 buttons enable positive values of C and G to be measured, but with a magnification factor for each term, of ten. This provides improved reading accuracy for small minor term values.

TRIM Controls

Capacitance or leakage between measurement cables or jigs would give rise to false zero readings. The TRIM potentiometers enable these effects to be balanced out.

Supply Switch

The Supply switch is a three position rotary switch engraved OFF, ON and BOOST CHARGE. The instrument is operational when this switch is set to the ON position, regardless of any connection to an a.c. supply, since an internal rechargeable battery is fitted. The instrument should be operated with the Supply switch in the BOOST CHARGE position if the internal battery is partially discharged, or if Ranges 1 or 2 are to be used for any length of time.

LINK NEUTRALS Switch

The two neutral leads are connected internally when this switch is in the up, LINK NEUTRALS, position. This facility simplifies the connection of Wayne Kerr Conductivity and Permittivity cells, since the majority of these cells are not fitted with a neutral link. This switch may also prove useful when using special jigs or fixtures for the connection of the test component, and for normal two terminal measurements where external linking of the neutrals may be inconvenient.

Preset Controls

A number of preset controls are contained within the instrument, the settings of which are carefully adjusted during manufacture and do not normally require further adjustment. It is important to note that none of these controls should be adjusted except as detailed in the Maintenance Manual. Failure to heed this warning may result in improper or inaccurate operation.

OPERATION

PRELIMINARY

Ensure that the voltage selector is set to the correct voltage tapping. The selector is a small two position slide switch mounted above the fuse in a cut-out in the back of the cabinet. A locking plate is fitted to prevent accidental operation of the switch. To alter the voltage range, remove the locking plate and slide the switch into the opposite position; reverse the locking plate and refit. Engraving on this plate indicates the voltage range available, 120V for the range 100–125V, and 240V for the range 200–250V. The fuse mounted just below the switch is the power supply fuse; a suitable replacement (for 120 or 240V supplies) is Beswick type TDC134, 0.5A “slow blow”.

SWITCHING ON

The instrument is supplied with a three wire connecting lead for the a.c. supply, terminated with a three pin free socket at one end. This should be inserted into the input plug at the rear of the instrument. The free end of the lead should be fitted with a suitable three pin plug. Connect red (or brown) to live, black (or blue) to neutral and green (or green striped yellow) to ground. (Two colour codes are in

use).

The power supply incorporates a rechargeable DEAC nickel-cadmium battery. This battery is float charged when the instrument is connected to an a.c. supply line and switched on. (Ensure that the neon indicator, mounted to the right of the Supply Switch, is glowing—if it is not, check the power supply fuse).

Set the Supply switch to the **BOOST CHARGE** position if a rapid charge is required or whenever Ranges 1 or 2 are to be used for any length of time. Do not leave the Supply switch in the **BOOST CHARGE** position for more than 10 hours.

The battery is fully charged when the instrument leaves the factory but, because there is a tendency to self-discharge during periods of non use, it is advisable to use an a.c. line supply for the first 10 to 20 hours of operation (Supply switch in the **ON** position). This will restore the battery to its maximum capacity.

When fully charged, the battery will operate the instrument for approximately 15 hours on Ranges 3–10, or 10 hours on Ranges 1 and 2, before re-charging becomes necessary.

With no **UNKNOWN** connected to the measurement leads, set the Supply switch to **ON** or **BOOST CHARGE** as appropriate and allow the

instrument to stabilise for 1 minute before measurements are undertaken.

MEASUREMENT CABLES

The instrument is supplied with two pairs of measurement cables. One pair (Type D10065A) is terminated with crocodile clips at the test component end, the second pair (Type D10642B) being fitted with a special low capacity clip. This latter type should be used to obtain maximum accuracy when measuring small values of capacitance (Ranges 9 or 10).

The cables are connected to the UNKNOWN sockets E and I. The legend E signifies the voltage or source side of the instrument, while I signifies the current or detector side. In each case the green lead is the Neutral connection. The exposed metal sleeve between the two moulded sections is also connected to Neutral.

IMPORTANT: Under no circumstances must the inner of either measurement lead be connected to ground while the green wire of the a.c. power cable is grounded. The Neutral circuit of the instrument is grounded internally and such action would render the Bridge inoperative.

When it is necessary to connect the inner of either measurement lead to the chassis or framework of the equipment under test, this equipment must first be isolated from ground. If this is not practicable, isolate the instrument from ground by disconnecting the power cable, the instrument being operated under battery power for the duration of such measurements.

TRIMMING (Normal Measurements - Ranges 4 - 10)

Connect the measurement cables to be used to the UNKNOWN sockets E and I. Connect together the two green Neutral leads as shown in Fig. 1, or alternatively, set the LINK NEUTRALS switch to the upper position. Do not connect the test component Yu at this stage. Select Range 4, set all Decade Controls to zero and depress the C and G MULTIPLIER buttons bearing the legend 1. Adjust TRIM C and TRIM G to obtain minimum indication on the NULL indicating meter. Although the trimming conditions established on RANGE 4 will be approximately correct on RANGES 4-10, it is desirable always to check the trim on the RANGE finally selected for measurement, with the settings of the MULTIPLIER switches determined and any special jigs connected. This is particularly important

when measuring small values of capacitance and when changing leads from the standard type to the Low Capacitance Clip Leads. This check can be made very quickly as described below.

Disconnect either of the red leads (or either of the Low Capacity Clips) from one end of the UNKNOWN. (If a jig is in use, leave the measurement leads connected to the jig but disconnect one lead of the component from the jig). With all Decade Controls in zero positions, adjust TRIM C and TRIM G to obtain a null on the meter.

TWO TERMINAL MEASUREMENTS - RANGES 4 - 10

Normal Measurements

The following operations cover normal two terminal measurements at 1592Hz. Low Impedance measurements and three or four terminal measurements are dealt with under their respective headings. For measurements at other frequencies, see the section headed EXTERNAL SOURCE AND DETECTOR on page 29. For measurements on polarised capacitors, energised inductors and other special conditions, see the section headed BRIDGE MEASUREMENT TECHNIQUES on page 39.

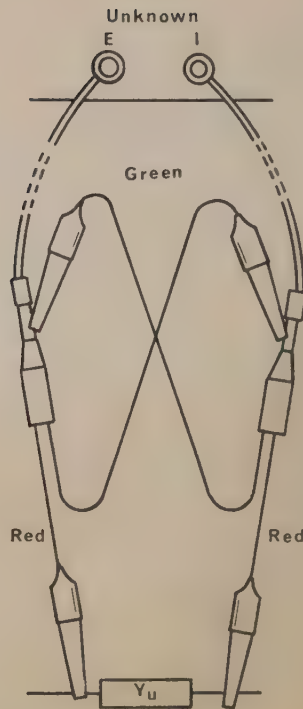


Fig. 1 Normal Measurement Connections

The basic procedure for normal measurements is the same regardless of the nature of the component under test. When the measurement is completed, interpret the displayed result as described in the next section. The user is advised to read through these two sections before commencing to use the instrument.

Having trimmed with all Decade Controls in the zero positions and RANGE 4 selected, connect the component to be measured between the two red leads terminated with crocodile clips (see Fig. 1.) or between the special clips if the Low Capacitance Leads are being used.

Depress the G MULTIPLIER button bearing the legend 1 for measurements of positive conductance or resistance.

Depress the C MULTIPLIER button bearing the legend 1 for measurements of capacitance, or the button bearing the legend -1 for measurements of inductance.

If the value of the test component is known approximately, set the RANGE switch to the appropriate range (see Specification, page 6) and trim the instrument on that range.

If the value of the test component is not known, move the RANGE switch from Range 4 through successive ranges until the largest on-scale meter

indication is obtained. If Ranges 9 or 10 are selected, temporarily disconnect the I lead from the component and check the trim.

Adjust the C and G Decade Controls alternately until the meter indication is at a minimum.

Read the C and G values directly from the displays, in conjunction with the decimal point indicator lamps. The displays give the equivalent parallel components of capacitance and conductance.

NOTES:

- (1) To obtain greater discrimination for the minor term, depress the appropriate C or G MULTIPLIER button bearing the legend 0.1. The displayed value must then be divided by 10.
- (2) If one term—whether C or G—predominates, the balance will be sharp and the final meter indication small. However, in some measurements, e.g. C and R in series where $X_c \simeq R$ and some inductance measurements, the null may not be so well defined. The condition may also occur if the measurement is made in the presence of a strong external electromagnetic field.
- (3) If a full scale (or greater than full scale) meter indication is obtained on RANGE 4, the component is of low impedance and requires a four terminal measurement (see page 21).

Interpretation of Results

The foregoing procedure applies basically to the measurement of any normal component (i.e. one whose value is within the scope of Ranges 4-10 inclusive).

If the component under test is a capacitor, the value of C is read directly from the display. The loss term given by the G display is the parallel conductance of the component. To interpret this value in terms of parallel resistance, use the following expressions.

For Ranges 4 & 5: $k\Omega = \frac{1}{m\Omega}$, for

Ranges 6-8: $M\Omega = \frac{1}{\mu\Omega}$ and for Ranges 9 & 10:

$G\Omega = \frac{1}{n\Omega}$ ($G\Omega = 1000M\Omega$). Reciprocal tables

are supplied at the back of this manual.

The dissipation factor of a capacitor and the Q factor of an inductor, on Multiplier 1 and at the internal source frequency of 1592Hz, can be found by taking the direct ratio of the C and G readings.

$$\tan \delta = \frac{G \text{ reading}}{C \text{ reading}} \quad Q = \frac{C \text{ reading}}{G \text{ reading}}$$

In nearly all cases the G MULTIPLIER button bearing the legend 1 will be depressed, for positive values of conductance. However, some networks

have a negative resistance characteristic in certain circumstances. Such cases may require the use of the -1 button.

A wirewound resistor may have an inductive reactance and this will require the use of the -1 C MULTIPLIER button. In this case it will be necessary to take the reciprocal of both displays since:—

$$R = \frac{1}{G} \text{ and parallel } L = \frac{1}{\omega^2 C}$$

where $\omega^2 = 10^8$ at 1592Hz

Alternatively, it may be more useful to interpret this as negative capacitance since this is a direct measure of the (positive) capacitance which, if connected in parallel with the UNKNOWN, would cancel out the inductive term at the measurement frequency. To obtain negative C, use the factor given by the RANGE switch position and prefix the result with a minus sign. If it is desired to express the two terms in the equivalent series form, conversion formulae (parallel to series) are given in the section headed PARALLEL TO SERIES CONVERSIONS on page 24.

If the test component is an inductor, the -1 C MULTIPLIER button should be depressed, before commencing the measurement procedure. To determine the effective value of the inductance, use the

expression given above.

The value of an inductor, as measured by the bridge, is its effective value, whereby the inductor self-capacitance is taken into account. However, if the self-capacitance of the inductor is known, it can be added numerically to the C readout (making the reading more negative) to give, after calculation by the above expression, a true value of inductance. The value of inductors is modified by their proximity to metal objects and so a free air space around the component should be ensured.

THREE TERMINAL MEASUREMENTS - RANGES 4 - 10

In-Situ Measurements

It is often convenient to be able to measure an impedance in-situ, without disconnecting any other components that may be associated with it. This applies particularly when components form part of a printed circuit or encapsulated assembly. Moreover, with certain test jigs, it is often impossible to 'disconnect' the effective shunt and stray capacitances. Generally speaking, any circuit can be resolved into a three terminal network, the arrangement being shown in Fig. 2.

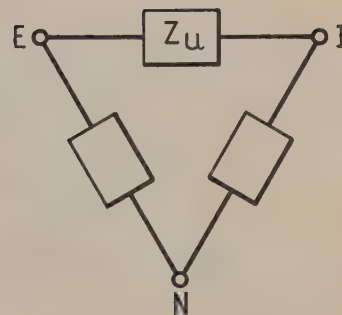


Fig. 2 Three-terminal Network

The impedance to be measured is Z_u and the effect of impedances E-N and I-N must be removed. The arrangement can be considered as a π -network and is shown in Fig. 3 in this form, connected to the bridge.

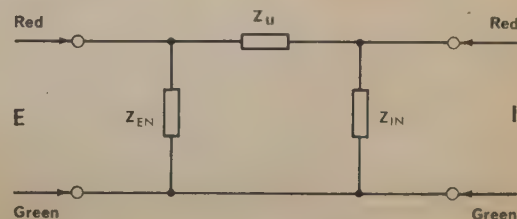


Fig. 3 Three-terminal Measurements

Z_{EN} shunts the E circuit and Z_{IN} shunts the I circuit. In many instances these shunting effects can be disregarded. In Fig. 4, for example, it may be possible to measure the impedance between A and B without disconnecting the other components, simply by connecting point C to the Neutrals.

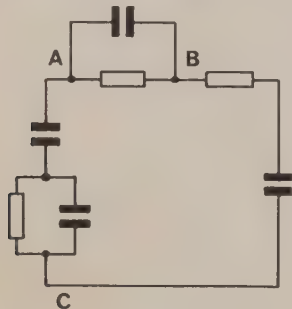


Fig. 4 In-situ Measurements

When the shunting effects (Z_{EN} and Z_{IN} of Fig. 3) cannot be ignored, the series resistance and leakage inductance of the bridge circuits must be taken into account. The measurement circuit must now be drawn as in Fig. 5 and a simple calculation, described in succeeding paragraphs, must be made to correct the readings obtained.

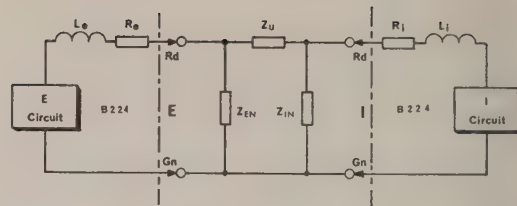


Fig. 5 Shunting Effects

The loading effect of the UNKNOWN impedance itself is small and can be ignored. It is only when the shunt impedances are low compared with Z_u that errors arising are of importance. Therefore Z_u can be considered as an open-circuit and the shunting effects on either side of the UNKNOWN can be considered separately.

The fall in potential at E caused by the load Z_{EN} will depend on the ratio of Z_{EN} to the impedance of R_e and L_e , the effective series resistance and inductance at the E socket. A similar argument applies to the detector (I) side of the bridge and the two effects are additive.

Table 1 gives the average values of effective resistance and inductance for each range. When it is necessary to correct for shunt loading the following formulae can be used to calculate the true value of

impedance Z_u , from the value read on the bridge Z_m .

With shunt loading on the E socket only:

$$Z_u = (1 - Z_e/Z_{EN}) \cdot Z_m$$

where $Z_e = R_e + j\omega L_e$ ($\omega = 10^4$ at 1592Hz).

With shunt loading on the I socket only:

$$Z_u = (1 - Z_i/Z_{IN}) \cdot Z_m$$

where $Z_i = R_i + j\omega L_i$.

With shunt loading on E and I sockets:

$$Z_u = [1 - (Z_e/Z_{EN} + Z_i/Z_{IN})] \cdot Z_m$$

RANGE	E SOCKET		I SOCKET	
	Re	Le	Ri	Li
4	30mΩ	0.29μH	24mΩ	0.29μH
5	30mΩ	0.29μH	30mΩ	0.5μH
6	90mΩ	0.65μH	30mΩ	0.5μH
7	90mΩ	0.65μH	900mΩ	100μH
8	900mΩ	2.0μH	900mΩ	100μH
9	900mΩ	2.0μH	43Ω	4mH
10	45Ω	4mH	43Ω	4mH
EXT. STD SOCKET	100mΩ	1μH	47mΩ	0.1μH

Table 1 Internal R and L for each Range (Typical)

Network and Attenuator Characteristics

The facility for three-terminal measurements and the readiness with which either or both the conductance and capacitance Standards can be made effectively negative by depressing the appropriate MULTIPLIER button makes the bridge a most efficient instrument for measuring the characteristics of networks. Transfer admittance, for example, is measured simply by the arrangement shown in Fig. 6. The input of the network is connected between the red and green E leads. The output is connected, in series with its terminating resistance R_T , between the red and green I leads. If there is no internal connection between the Neutrals in the circuit being measured, the LINK NEUTRALS switch may be set to the upper position.

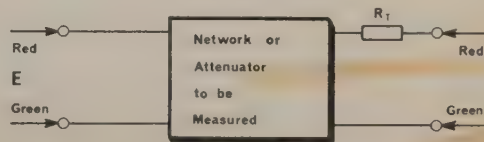


Fig. 6 Network and Attenuator Characteristics

The right-hand side of R_T will be at Neutral potential when the bridge is balanced and the network will then be correctly terminated.

Let the transfer admittance, defined as the current flowing in the terminating resistor for unit input voltage, be $|Y|/\angle\theta$. Then, at balance:

$$|Y|/\angle\theta = \pm G_m \pm j\omega C_m$$

where G_m and C_m are the values of conductance and capacitance read on the bridge.

Then $|Y| = (G_m^2 + \omega^2 C_m^2)^{\frac{1}{2}}$

and $\angle\theta = \tan^{-1} (\pm \omega C_m / G_m)$.

The characteristics of attenuators can be measured on the bridge using the same circuit arrangement as shown in Fig. 6. With the resistor R_T in the position shown the attenuator is correctly terminated at balance, when the right-hand side of R_T will be at Neutral potential.

If the bridge is balanced with the attenuator set to zero, a value equal to the matching impedance R_T will be measured. If the attenuator steps are now switched in, the voltage attenuation can be calculated accurately from the ratio of the apparent change in value of R_T .

Measurement of Screened Components

When a component, such as a small-value capacitor, is mounted in a screening box, the Neutral connection from the bridge should be connected to the box. One green lead should remain cross-connected (from E to I, or vice versa) and the second green lead provides the desired Neutral connection.

Measurement of Three Terminal Capacitors

When measuring sub-standard three-terminal capacitors, care must be taken to ensure that the conditions of measurement are the same as those under which the capacitor was calibrated. A three-terminal capacitor is shown schematically in Fig. 7.

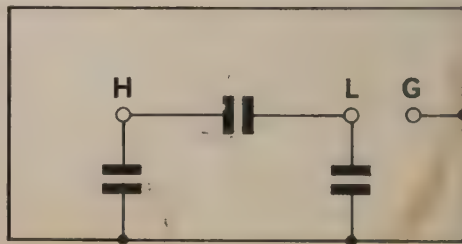


Fig. 7 Three-terminal Capacitor

Where the case has been connected to one terminal during calibration, then the L and G terminals should be connected to the I lead. If, however, the direct capacity only is required, then the G terminal should be connected to the Neutral.

FOUR TERMINAL MEASUREMENTS - RANGES 1 - 3

General

This section describes four-terminal measurement of low impedance components. At 1592Hz the coverage provided by this method is resistance less than $10\ \Omega$ (conductance exceeding 100mS), inductance less than 1mH and capacitance exceeding $10\mu\text{F}$. For values outside these limits, refer to the section headed TWO-TERMINAL MEASUREMENTS—RANGES 4-10 on page 14. For operation at other frequencies, see the section headed EXTERNAL SOURCE AND DETECTOR on page 29.

Trimming (Low Z)

Ensure that the LINK NEUTRALS switch is in the lower position. Connect the crocodile-clip leads to the UNKNOWN sockets. Remove any connections from all other front-panel sockets.

Clip the red and green leads from the left-hand cable (looking at the front-panel connectors) one to

either side of the component to be measured, at least $\frac{1}{2}$ inch from the body (see Fig. 8).

Clip the green lead from the right-hand cable to

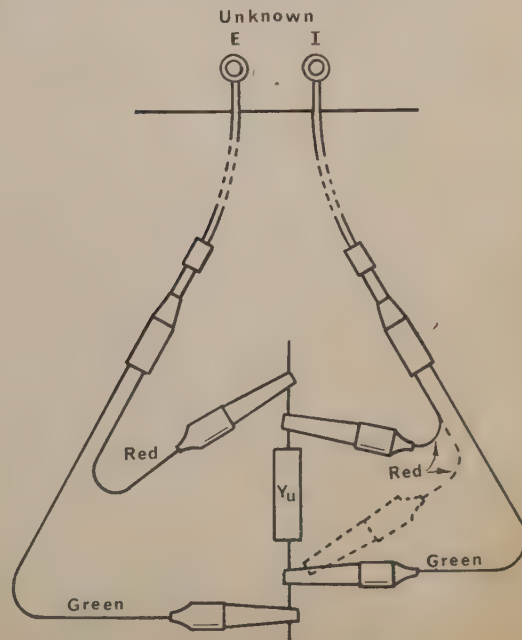


Fig. 8 Low Impedance Measurement Connections

the component wire between the body and the left-hand green lead clip.

Clip the red lead of the right-hand cable on to the clip of the green lead from the same cable.

Select RANGE 1 and set all Decade controls to the zero position and depress the C and G MULTIPLIER buttons bearing the legend 1.

Adjust TRIM C and TRIM G to obtain minimum indication on the NULL indicating meter.

Transfer the red lead of the right-hand cable to the other side of the component body so that the clip is between the body and the left-hand red clip (Fig. 8).

The instrument is now ready for use. Set the RANGE switch commencing on RANGE 1, and advancing from 1-3 as required, until the largest on-scale meter indication is obtained. When the correct RANGE has been selected, the instrument should be retrimmed. Measurements are then made with the red I lead returned to the top of the component (Fig. 8), the Decade Controls being used to produce a null on the meter.

N.B.—The measurement is ALWAYS that between the two clips from the right-hand cable (the other pair of clips being always outside these). Thus, for example, it is possible to measure the resistance per unit length of conductors.

Resistance Measurement (Low Z)

The procedure is basically the same as for NORMAL MEASUREMENTS (Resistance) except that

- (a) on LOW IMPEDANCE only, the C MULTIPLIER button bearing the legend -1 should be depressed if any capacitance is present, and the 1 button used if inductance is present (i.e. opposite settings to those for Normal Measurements);
- (b) the bridge reads the equivalent SERIES impedance of the UNKNOWN.

The G display reads in resistance units as indicated on the Range switch, in conjunction with the decimal point indicator lamps.

On the Low Impedance RANGES 1-3 the values derived from the bridge readings are the equivalent SERIES components of R and L, or R and C.

Inductance Measurement (Low Z)

The procedure is the same as given in preceding paragraphs for resistance measurement, bearing in mind that, on RANGES 1-3 only, the MULTIPLIER button bearing the legend 1 is depressed for inductance measurements. The value is obtained from the C display by using the units of inductance indicated on the RANGE switch.

Table 2 External Standards

UNKNOWN ARM				EXTERNAL STANDARD Value equivalent to full scale on Normal Range of Unknown				
Unknown Value	Normal Range	E & I turns in Unknown Arm	Normal Discrimination	For Normal Discrimination (Select Normal Range)	10 × Normal Discrimination (Select 1 Range above Normal)		100 × Normal Discrimination (Select 2 Ranges above Normal)	
					New Range		New Range	
1μF-10μF 10mΩ-100mΩ	Range 4	E + 1, I + 1	1nF, 10μΩ	10nF 100μΩ	Range 5	100nF 1mΩ	Range 6	1μF 10mΩ
100nF-1μF 1mΩ-10mΩ	Range 5	E + 1, I + 10	100pF, 1μΩ	10nF 100μΩ	Range 6	100nF 1mΩ	Range 7	1μF 10mΩ (Direct comparison)
10nF-100nF 100μΩ-1mΩ	Range 6	E + 10, I - 10	10pF, 100nΩ	10nF 100μΩ	Range 7	100nF 1mΩ (Direct comparison)	Range 8	1μF 10mΩ
1nF-10nF 10μΩ-100μΩ	Range 7	E + 10, I + 100	1pF, 10nΩ	10nF 100μΩ (Direct comparison)	Range 8	100nF 1mΩ	Range 9	1μF 10mΩ
100pF-1nF 1μΩ-10μΩ	Range 8	E + 100, I + 100	100fF, 1nΩ	10nF 100μΩ	Range 9	100nF 1mΩ	Range 10	1μF 10mΩ
10pF-100pF 100nΩ-1μΩ	Range 9	E + 100, I + 1000	10fF, 100pΩ	10nF 100μΩ	Range 10	100nF 1mΩ	NO RANGE AVAILABLE	
1pF-10pF 10nΩ-100nΩ	Range 10	E - 1000, I + 1000	1fF, 10pΩ	10nF 100μΩ	NO RANGE AVAILABLE		NO RANGE AVAILABLE	

One minor division on the meter always equals 1/10⁴ of the selected range maximum.

specifies the increase in RANGE setting required (the RANGE position is increased by one for each extra order of discrimination).

4. The three columns give the values of EXTERNAL STANDARD equivalent to full range capability on the normal range for the unknown component.

If the UNKNOWN value is less than full range capability, the EXTERNAL STANDARD value must be reduced proportionally.

The above method holds in principle for RANGES 4-10. In practice, however, a limit is reached on the high ranges when no further ranges are available to increase the discrimination and, on the low ranges, when the heavy loading that occurs will exaggerate the errors caused by internal and lead impedances.

Having determined the correct value for the EXTERNAL STANDARD and the required RANGE, the measuring procedure is the same as before, i.e. the bridge is trimmed on the new range with only the leads connected, the zero Decade positions selected, both components connected and normal measurement carried out.

Interpretation of Results

Within the limits of accuracy obtainable, the

bridge always indicates the difference between the admittance of the UNKNOWN arm and the admittance of the EXTERNAL STANDARD arm transformed up or down to the level of the UNKNOWN arm.

The EXTERNAL STANDARD is reflected into the UNKNOWN arm as a negative admittance transformed by the ratio of the UNKNOWN E and I turns product to the External Standard E and I turns product. Thus:

Effective Value of EXTERNAL STANDARD reflected into UNKNOWN arm

$$= \frac{\text{Ext. Std. value} \times \text{Ext. Std. turns product}}{\text{Unknown turns product}}$$

The turns product of the UNKNOWN arm is dependent only on the RANGE setting and can be found from Table 2. The turns of the EXTERNAL STANDARD arm are E-100 and I+10, when a positive MULTIPLIER button is depressed.

Bridge indication = Unknown value—

$$\frac{\text{Ext. Std. value} \times \text{Ext. Std. turns product}}{\text{Unknown turns product}}$$

The bridge indication is always taken in conjunction with the multiplier of the range actually in use.

When a -1 MULTIPLIER button is depressed

to balance the bridge, this implies that the UNKNOWN admittance is less than the reflected admittance of the EXTERNAL STANDARD. The above equation holds if the bridge indication is taken as a negative value.

Extension of Trim

It is sometimes necessary to trim out the effects of special clips, jigs, etc. or even an unwanted shunt path that appears, effectively, across the UNKNOWN. In cases where the coverage of the TRIM controls provided is inadequate or inconvenient, a suitably chosen component may be connected to the EXTERNAL STANDARDS sockets. The required value is best obtained by measuring the shunt path on the bridge and referring to the 'Normal Discrimination' columns in Table 2, exactly as if a comparator measurement were intended.

EXTERNAL SOURCE & DETECTOR

General

The B224 internal source operates at a fixed frequency which is, normally, 1592Hz ($\omega = 10^4$). When operation is essential at other frequencies, an external source must be employed.

The internal detector is a wide band amplifier

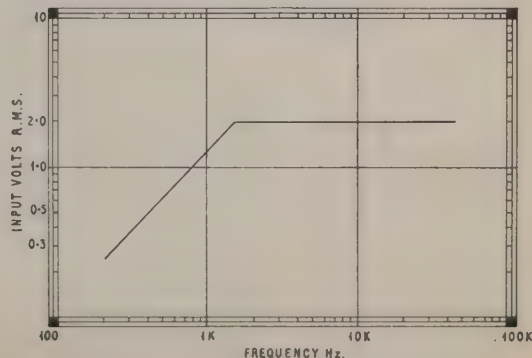
whose frequency response extends from 200Hz to 50kHz. Thus the instrument can be operated at any frequency between these limits without the need for an external detector.

In some applications an external detector is preferable and a socket for this purpose is provided on the rear panel.

The illuminated decimal points associated with the decades will still be operational, provided that the instrument is connected to an a.c. power supply.

Source

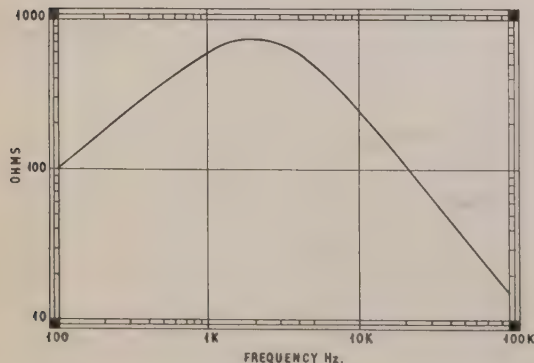
The correct external source level for any fre-



Graph 2 Maximum drive at External Source Socket plotted against frequency (Typical)

quency can be found by reference to Graph 2. Higher levels can cause errors and possible damage to the instrument, while lower levels will reduce the sensitivity. The output from the source must be free of d.c.

The input impedance at the EXTERNAL SOURCE socket varies with frequency and this is illustrated in Graph 3. Any source employed should be capable of driving this impedance without distortion. If distortion is present, and an inductor is being measured, a tuned external detector will be



Graph 3 Input Impedance at External Source Socket (Typical)

required, since although the bridge may be balanced at the fundamental measuring frequency, it will be unbalanced at the harmonic frequencies.

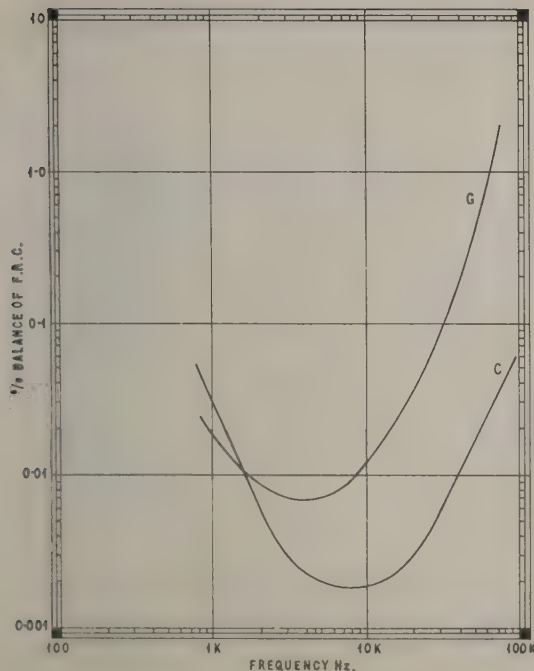
Detector

The internal detector may be used in conjunction with an external source over the frequency range 200Hz to 50kHz and is perfectly satisfactory for the majority of measurements, particularly when the measured term is pure. Graph 4 shows the degree of imbalance that will give a detectable meter deflection. The curves are thus an indication of the sensitivity of the system. To avoid confusion between ranges, the degree of imbalance (i.e. the vertical axis) is given as a percentage of the range maximum or full range capability (f.r.c.). A constant input level of 2.0V r.m.s. is assumed.

A tuned external detector is recommended when one or more of the following conditions apply

- (a) Distorted source waveform (not purely sinusoidal).
- (b) Measurement of non linear components.
- (c) Measurement of inductance.

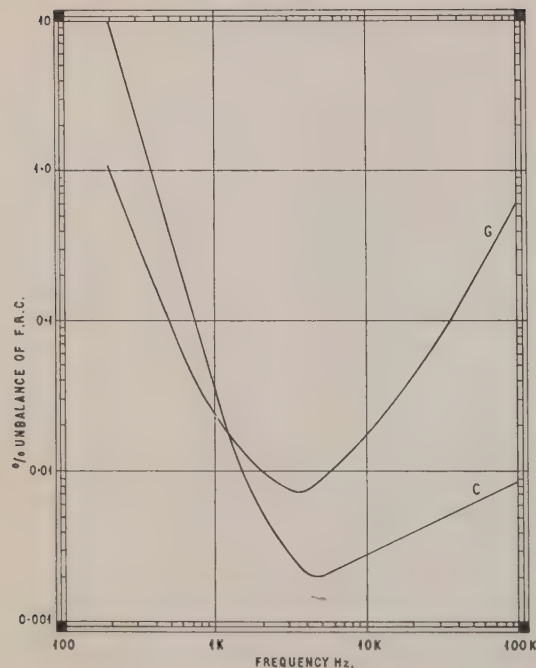
The choice of detector will depend to a large extent on the degree of discrimination required, which in turn dictates the accuracy of the final result. In general the greater the detector sensitivity,



Graph 4 Bridge Sensitivity using Internal Detector when fed with 2V r.m.s. at External Source Socket (Typical)

the greater the degree of discrimination available. In practice, however, there is a limit to the sensitivity that can be used, due to residual hum and noise both within the bridge and in the external detector. The residual noise level is not constant over the useful frequency range, most notable being peaks at the fundamental and low order harmonics of the a.c. line frequency. Tuned detectors reduce noise and attenuate harmonics, producing a considerable improvement in the accuracy of results when measuring inductors. A detector having a single tuned circuit with a Q of 20 will provide adequate rejection of noise and source harmonics over the useful frequency range. In general, a detector providing full scale deflection for 5mV at the EXTERNAL DETECTOR socket will realise the maximum useful sensitivity, since hum and noise may represent 2.5mV at some frequencies.

Graph 5 illustrates the sensitivity of the system over the useful frequency range, and should be interpreted as follows. If the instrument is at exact balance, there will be zero output at the EXTERNAL DETECTOR socket (excluding residual noise). If, however, the balance is in error by an amount sufficient to produce 5mV at the EXTERNAL DETECTOR socket, then Graph 5 will show the size of the imbalance, i.e. the discrimination for



Graph 5 Typical % Unbalance for 5mV r.m.s. at External Detector Socket when B224 is fed with Maximum Input Volts

5mV output and pro rata. This graph should be consulted when interpreting the accuracy of results. It is important to note that the figures given are a percentage of the full range capability of the range in use.

Since the EXTERNAL DETECTOR socket is fed from a point within the internal detector, the instrument must be switched ON, even though both external source and detector are in use. Insertion of the EXTERNAL SOURCE jack disconnects the supply to the internal source, thereby reducing current consumption to negligible proportions. It is therefore permissible to operate from battery power only, even if the instrument is to be operated on RANGES 1 and 2. The internal detector is operational when an external detector is in use.

Operation

When making measurements using an external source and detector at frequencies other than 1592Hz, it is helpful to have an approximate idea of the expected measurement value. This will enable the correct RANGE to be selected and therefore reduce the length of time taken to arrive at balance. If the value of the test component is not known, the component may be measured at 1592Hz using

the internal source and detector. This will enable the correct RANGE to be predicted.

Method 1 (using the internal detector)

Connect the source to the EXTERNAL SOURCE socket, tune to the desired measurement frequency and adjust the level as shown in Graph 2. Set the Supply switch to ON and set all Decade controls to the zero positions. The instrument may be operated from the internal battery only, if required. Determine the expected RANGE and set the RANGE switch to the required position. Connect the appropriate measurement cables and connect as for trimming. The instrument is trimmed exactly as described in the section headed TRIMMING (Normal Measurements—Ranges 4–10) on page 13, or TRIMMING (Low Z) on page 21. The measurement is now made in the normal manner.

Method 2 (using an external tuned detector)

Connect the source to the EXTERNAL SOURCE socket, tune to the desired measurement frequency and adjust the level as shown in Graph 2. Set the Supply switch to ON, the second G Decade control to 1 and all other Decade controls to the zero positions. The instrument may be operated from

the internal battery only, if required. Connect the detector to the EXTERNAL DETECTOR socket and tune the detector for maximum indication on the external detector, adjusting the attenuator to retain an on-scale reading. Set the 2nd G Decade control to zero.

Determine the expected range and set the RANGE switch to the required position. Connect the appropriate measurement cables and connect as for trimming. The instrument is trimmed exactly as described in the section headed TRIMMING (Normal Measurements—Ranges 4–10) on page 13, or TRIMMING (Low Z) on page 21, except that TRIM C and TRIM G are adjusted for minimum indication on the external detector.

The measurement is now made in the normal manner, except that the Decade controls are adjusted for minimum indication on the external detector, the attenuator being adjusted to obtain a more sensitive indication as balance is approached. The indication on the B224 NULL meter should be disregarded.

NOTES:

1. When the instrument is operated from the internal battery, the decimal point indicator lamps are not illuminated. The correct position for the decimal point can be found by

reference to columns 1 and 2 of Table 2 on page 27.

2. The disposition of the leads during trimming and measurement, the use of Low Capacity Clips and allowance for the series inductance of the leads and the bridge circuits, all become increasingly important at the higher frequencies.

Interpretation of Results

Measurements of inductance and resistance Ranges 1-3 and conductance and capacitance Ranges 4-10 are not frequency dependent. The results are therefore interpreted as with internal source and detector, in conjunction with the RANGE switch units and the decimal point indicator lamps.

For measurements of inductance Ranges 4-10, and measurements of capacitance Ranges 1-3, a factor dependent on frequency must be applied.

For inductance, Ranges 4-10
$$L = \frac{1}{\omega^2 C}$$

where $\omega = 2\pi f$ and C is the value obtained after using the RANGE multiplying factor. The units are basic (L in Henrys, C in Farads). Thus, 10^{-6} must be included if C is in μF , 10^{-9} for nF, 10^{-12} for pF

and 10^{-15} for fF. The expression can be written as

$$L = 1/(39.48f^2C)$$

For capacitance, Ranges 1-3
$$C = \frac{1}{\omega^2 L}$$

where $\omega = 2\pi f$ and L is the value obtained after using the RANGE multiplying factor. The units are again basic, (L in Henrys, C in Farads).

Accuracy

Bridge accuracy using the internal source/detector on Ranges 4-10 is 0.1% on C and G provided all decades are in use. Measurement of L is dependent on a precise knowledge of the bridge frequency, which is accurate to 1%. The C and G accuracy obtainable at other frequencies is better than

$$\pm 0.1\% \quad 200\text{Hz} - 10\text{kHz}$$

$$\text{Typically } 0.25\% \text{ at } 20\text{kHz}$$

$$2\% \text{ at } 50\text{kHz}$$

These figures apply also to L measurement where frequency is known accurately: otherwise allowance must be made [L will vary as $1/(\text{frequency})^2$]. Low Impedance accuracy is given by adding 0.2% to the

figures quoted above, after allowance for systematic error. In this case the figures apply to L and R. For C, measure frequency or make due allowance [C will vary as $1/(\text{frequency})^2$].

Note.—On the Low Impedance Ranges 1–3, correction for systematic error must be made. (See Graph 1 and the section headed Accuracy of Low Impedance Measurements, on page 24).

Range Limitations

Permissible bridge loading restricts the maximum capacitance that can be measured accurately at frequencies above 1592Hz on Ranges 4–10. However, it should be noted that as the frequency is increased, this restriction in the bridge coverage is accompanied by a corresponding extension in the measurement range of the Low Impedance Ranges 1–3.

Table 3 provides a guide to the maximum capacitance and minimum inductance values that can be measured accurately on the bridge, at selected frequencies throughout the band, on Ranges 4–10. In all instances lead corrections must be applied when the admittance of the UNKNOWN exceeds 10 milliohms (i.e. when the impedance is less than

100 ohms)—see the section headed LEAD CORRECTIONS on page 36.

When the bridge is used on Ranges 9 or 10 (for the measurement of large values of resistance and/or reactance) at frequencies above 2000Hz, particular care must be taken to avoid heavy shunt loading to the Neutral from either the voltage or current leads. If such loading is present, the measured value of the UNKNOWN should be corrected using the formulae given in the section headed In-Situ Measurements on page 17.

Table 3 Range Limitations with Frequency (Ranges 4–10)

Source Frequency	Maximum Capacitance	Minimum Inductance
200Hz	10 μ F	63mH
400Hz	10 μ F	16mH
800Hz	10 μ F	4mH
1000Hz	10 μ F	2.5mH
1592Hz	10 μ F	1mH
2kHz	8 μ F	0.8mH
4kHz	4 μ F	0.4mH
8kHz	2 μ F	0.2mH
10kHz	1.6 μ F	0.16mH
15kHz	1 μ F	0.11mH
20kHz	0.8 μ F	0.08mH
30kHz	0.5 μ F	0.055mH
40kHz	0.4 μ F	0.04mH
50kHz	0.32 μ F	0.032mH

MEASUREMENT CONDITIONS

The voltage applied to the UNKNOWN during measurement is approximately as follows:

Ranges 4 and 5	65mV pk-pk
Ranges 6 and 7	650mV pk-pk
Ranges 8 and 9	6.5V pk-pk
Range 10	65V pk-pk

On the Low Impedance Ranges 1-3, measurements are made using a constant current source. The current passed through the UNKNOWN is approximately as follows:

RANGE 3	3mA pk-pk
RANGE 2	9mA pk-pk
RANGE 1	30mA pk-pk

LEAD CORRECTIONS

When the instrument is used on Ranges 4 or 5, for the measurement of conductance exceeding $10\text{m}\mathcal{G}$ (resistance of less than $100\ \Omega$), capacitance exceeding $1\mu\text{F}^*$, or inductance of less than 10mH^* ; an allowance must be made for the series resistance and inductance of the measurement cables and bridge circuits, in order to realise the full accuracy of the instrument.

*That is, reactance less than $100\ \Omega$. Values quoted apply at 1592Hz and must be computed for other measurement frequencies. The effect of shunt loading is described in the section headed In-Situ Measurements, on page 17.

Typical values are $130\ \text{m}\Omega$ and $2.3\ \mu\text{H}$ for Range 4, and $180\ \text{m}\Omega$ and $2.8\ \mu\text{H}$ for Range 5†. These figures are the sum of the measurement cables and the internal bridge circuits. The series resistance and inductance of the internal bridge circuits can be found from Table 1, in the section headed In-Situ Measurements, on page 19. For extreme accuracy, or when using leads other than those supplied with the instrument, it is advisable to measure the series resistance and inductance as described below.

The simplest method for making the correction is dependent on the availability of a second component whose value is within 2% of the value of the UNKNOWN. The Bridge is trimmed and the UNKNOWN measured normally, the conductance and capacitance values ($G1$ and $C1$) being noted. A further measurement is made with the UNKNOWN remaining in position, but with the second component connected between the red and green leads of the E cable. New readings ($G2$ and $C2$) are noted.

The second component is then transferred to the red and green leads of the I cable (the UNKNOWN remaining across the two red leads) and readings

†The values quoted are for measurement cables Type BML12. If the earlier cables Type BML3 are used, they should be measured as described.

(G3 and C3) again noted. The total effect of the second component is given by adding the two variations from the original, i.e. $(G1-G2) + (G1-G3)$ and $(C1-C2) + (C1-C3)$. The original reading is corrected by adding the appropriate sum. If the UNKNOWN—and therefore the loading component—is a capacitor, the effect will be to increase the C reading. The correction must then be added to the original reading.

An alternative method relies only on the availability of two $10\ \Omega \pm 2\%$ resistors. However, although the result is general, a calculation is necessary with each new measurement in order to apply the correction. The sequence of operations is similar to the previous method.

1. Measure one $10\ \Omega$ resistor, noting G1 and -C1.
2. Add second $10\ \Omega$ between red and green leads of the E cable. Rebalance and note G2 and -C2.
3. Leaving the first resistor across red-red, transfer second resistor to red and green of I cable. Rebalance and note G3 and -C3.

The differences that occur on adding the second resistor on the E side, are a measure of the series resistance and inductance of the leads and bridge circuits on that side. Similarly for the I side.

Resistance. When measuring 10 ohms on RANGE 4, using all decades, the difference between two conductance readings in mhos $\times 100$ gives the series resistance directly in milliohms.

Total series resistance = $[(G1-G2) + (G1-G3)] \times 100\text{m}\Omega$. To apply the correction, the measured value of the UNKNOWN should first be converted to the series form (see the section headed PARALLEL TO SERIES CONVERSIONS, on page 24) and the total series lead and circuit resistance subtracted.

Inductance. When measuring 10 ohms on RANGE 4, using all decades, the difference between two capacitance readings in $\mu\text{F} \times 100$ will give the series inductance directly in microhenrys.

Total series inductance = $[(-C1)-(-C2)] + [(-C1)-(-C3)] \times 100\mu\text{H}$.

To apply the correction for inductance measurements, the measured value of the UNKNOWN should first be converted to the series form and the total series lead and circuit inductance subtracted. For capacitive UNKNOWN measurements on RANGE 4, the capacitance value measured must be converted to a series capacitive reactance, and the inductive reactance of the leads and circuits added. The true series or parallel capacitance can then be calculated.

NOTE:

$$L_s (\text{true}) = \frac{1}{\omega^2 C_p (1 + 1/Q^2)} - L_T$$

For capacitance

$$X_s (\text{true}) = \frac{1}{\omega C_p (1 + 1/Q^2)} - \omega L_T$$

$$C_s (\text{true}) = \frac{1}{\omega X_s (\text{true})}$$

where L_T is the total series inductance of leads and circuits.

Worked Example for RANGE 4:

1. Measurement of 10 Ω resistor:

$$G1 = 98.31 \text{ m}\Omega; -C1 = -0.038 \mu\text{F}$$

2. Measurement with E cable loaded:

$$G2 = 97.49 \text{ m}\Omega; -C2 = -0.054 \mu\text{F}$$

3. Measurement with I cable loaded:

$$G3 = 97.77 \text{ m}\Omega; -C3 = -0.051 \mu\text{F}$$

Total series resistance:

$$= [(98.31 - 97.49) + (98.31 - 97.77)] \times 100 \text{ m}\Omega$$

$$= (0.82 + 0.54) \times 100 \text{ m}\Omega$$

$$= (1.36) \times 100 \text{ m}\Omega$$

$$= 136 \text{ m}\Omega$$

Total series inductance

$$= [(-0.038 + 0.054) + (-0.038 + 0.051)]$$

$$\times 100 \mu\text{H}$$

$$= (0.016 + 0.013) \times 100 \mu\text{H}$$

$$= 2.9 \mu\text{H}$$

Assume hypothetical bridge indications such as might be obtained when measuring a small inductor.

$$G = 97.43 \text{ m}\Omega \text{ and } C = -2.706 \mu\text{F}$$

These are parallel components and must be converted to equivalent series values.

$$Q = \omega C/G = \frac{10^4 \times 2.706 \times 10^{-6}}{97.43 \times 10^{-3}}$$

$$= \frac{27.06}{97.43}$$

$$= 0.278$$

$$\therefore Q^2 = 0.0077$$

Equivalent series resistance

$$R_s = 1/G(1 + Q^2)$$

$$= 1/97.43 \times 10^{-3} (1 + 0.0077)$$

$$= 9.53 \Omega$$

Equivalent series inductance

$$L_s = 1/(-\omega^2 C(1 + \frac{1}{Q^2}))$$

$$= 1/10^8 \times 2.706 \times 10^{-6} (1 + \frac{1}{0.0077})$$

$$\begin{aligned}
 &= 1/10^2 \times 2.706(1 + 12.99) \\
 &= 1/270.6 \times 13.99 \\
 &= 0.0002641 \\
 &= 264.1 \mu\text{H}
 \end{aligned}$$

Corrected series resistance

$$\begin{aligned}
 \text{True } R_s &= 9.530 - 0.136 \Omega \\
 &= 9.394 \Omega
 \end{aligned}$$

Corrected series inductance

$$\begin{aligned}
 \text{True } L_s &= 264.1 - 2.9 \mu\text{H} \\
 &= 261.2 \mu\text{H}
 \end{aligned}$$

If desired, these values can be converted back to parallel values by applying the formulae:

$$R_p = R_s(1 + Q^2)$$

$$C_p = C_s[1/(1 + \frac{1}{Q^2})]$$

$$L_p = L_s(1 + \frac{1}{Q^2})$$

When measuring capacitance, it is convenient to convert the lead reactance to a series capacitance. The required value of the UNKNOWN is then given by

$$C_u = \frac{C1 \times Cb}{C1 - Cb}$$

where C1 is the equivalent series capacitance of the leads, and Cb is the indication given by the bridge.

Corrections for Range 5. The method for obtain-

ing the series resistance of leads and bridge circuits is exactly the same as described for RANGE 4 but in this case a $100 \Omega \pm 2\%$ or better is measured with $10 \Omega \pm 2\%$ resistor loading.

The appropriate expressions for RANGE 5 are:

Series Resistance in milliohms = Total change in reading (mMho) $\times 1000$.

Series Inductance in microhenrys = Total change in reading in nF.

BRIDGE MEASUREMENT TECHNIQUES

Introduction

The Operating Instructions given for this instrument describe the basic procedure for directly measuring the quantities C and G, and deriving values for the quantities L and R. However, there are many cases where other parameters or conditions can be measured by adapting the basic procedure to meet the requirements of the individual case. While it is difficult to foresee every possible measurement, the intention in the following paragraphs is to indicate the approach to some of the more common applications so that users can obtain the full benefits of a.c. bridge measurement techniques. The Wayne Kerr Company is always inter-

ested in, and would be grateful for, any information concerning novel applications of this instrument. Users are also invited to consult the Company concerning problems arising in the course of such applications.

Measurements on Non-Linear Resistive Elements

When measuring the characteristics of non-linear resistive elements (e.g. thermistors) it must be borne in mind that the voltage applied to the UNKNOWN varies according to the measurement range in use. The applied voltage is given in the section headed MEASUREMENT CONDITIONS, on page 36.

NOTE—An external source may be used to provide a variable level for measurements of non-linear components.

Ceramic Capacitors - Ranges 4 - 10

With certain capacitors, the value changes considerably with the value of d.c. polarising voltage. In such instances a polarising potential can be applied as shown in Fig. 9 but the Link Neutrals switch must NOT be up. The bypass capacitor C_x should have a value at least 1000 times that of the UNKNOWN in order to reduce the additional error introduced to less than 0.1 %.

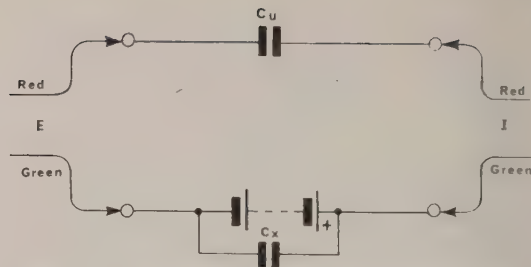


Fig. 9 Polarising Ceramic Capacitors (Ranges 4-10)

If one side of the d.c. supply is grounded, this should be connected to the green lead of the E cable, since this point is grounded internally.

Electrolytic Capacitors—Ranges 1-3

In practice it has been found that measurements of electrolytic capacitors may be made without using a polarizing voltage. In the majority of cases, the impedance of the component under test will require a four-terminal measurement. Should it be desired to use a polarising voltage, the connection should be made as in Fig. 10 the Link Neutrals switch must be down and the measurement made in the normal manner. The source of d.c. employed must not exceed an e.m.f. of 6V. A capacitor C_x is required to by-pass the series impedance of the polarising supply. The minimum value of C_x can be found from Table 4. When operating at other

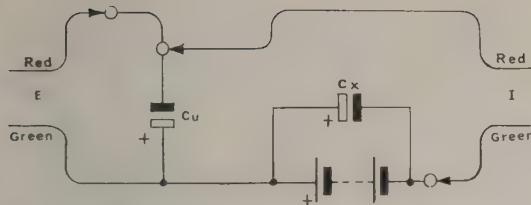


Fig. 10 Polarising Electrolytic Capacitors—Ranges 1-3

than the internal source frequency, the minimum value of C_x must be calculated from the following formula.

$$C_x = C_o \times \frac{f_o}{f} \text{ where } f_o = 1592\text{Hz.}$$

This will give an additional error of not more than 0.1%.

Table 4 C_o = Value of C_x at 1592Hz for Circuit of Fig. 10

RANGE	VALUE OF C_o
1	1000 μ F
2	300 μ F
3	100 μ F

If one side of the d.c. supply is grounded, this should be connected to the green lead of the E cable, since this point is grounded internally. The polarising of the capacitors must be arranged to suit.

The arrangement shown in Fig. 10 is suitable for positive grounding, or an ungrounded d.c. supply.

Loss Angle

The loss angle or power factor of capacitors can be computed from the values measured on the bridge.

$$\tan \delta = G/\omega C$$

$$\cos \theta = G/Y \simeq G/\omega C = \tan \delta$$

An allowance for the impedance of the measuring leads must be made when dealing with large-value capacitors.

The internal capacitance standards have a small loss term that will cause an error in the displayed G value of the test component. While this error is not normally significant (less than 1% offset of the third Decade reading) it may become so if an accurate measurement of a small loss term is required. The error will always be negative, i.e. the displayed G value will be less than the true value, but its magnitude can be simply determined as follows.

A standard air-dielectric capacitor, having either a negligible or known loss angle is measured on the bridge. The known loss angle (if any) is subtracted from the loss angle calculated from the displayed G and C values and the result is the error caused by

the loss angle of the internal standard. The final value thus obtained must be numerically added to any loss angles subsequently derived.

Iron-Cored Inductors

Great care must be taken when interpreting the results obtained from measurements on iron-cored coils and transformer windings. With power transformers, for example, the core will have only its initial permeability due to the low value of the a.c. potential applied from the bridge. The effective permeability at full operating voltage may be as much as twenty times higher.

With high-permeability materials such as mu-metal, the effective permeability changes so rapidly with excitation, even at very low levels of magnetization, that widely different values of inductance may be obtained on different ranges of the bridge or even on two bridges of the same pattern. Therefore, unless the operating conditions are simulated, the measurements made are of value only for comparison purposes.

Inductors Carrying D.C.

It is often necessary to measure inductors carrying a known value of direct current and this may be accomplished with the circuit of Fig. 11. With the arrangement shown and with the Link Neutrals switch down, the d.c. supply is connected between the two neutral leads. The limiting resistor R_{LIM} must be selected so that the current flowing does not exceed the value given for each range in Table 5. Alternatively a current limited supply may

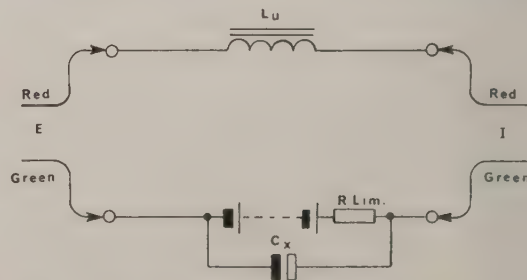


Fig. 11 Inductors Carrying D.C. (Ranges 4-10)

be employed. If the reactance of the by-pass capacitor, C , is significant, it can be allowed for by calculating its equivalent inductance value at the frequency in use, and adding this to the effective series value derived from the measurement. If one

side of the d.c. supply is grounded, this should be connected to the green lead on the E side of the bridge, since this is grounded internally.

Table 5 Maximum Permissible Current through Bridge

Range	4	5	6	7	8	9	10
Max. d.c.	1.0A	1.0A	300mA	30mA	30mA	3mA	3mA

Temperature Coefficients

Since leads of any length may be used without their capacitance affecting the accuracy of the reactance measurement, and as lead resistance can be allowed for, the bridge is ideal for the measurement of temperature and other coefficients of components placed in an oven, refrigerator, pressure chamber, humidity chamber, etc. If full use is made of the decades, normal discrimination of balance is 0.01 % of maximum for the range in use. If greater discrimination is required, see the section headed Increased Discrimination—Ranges 4–10, on page 26.

Measurements on Transformers

Turns Ratios

The turns ratio of a.f. transformers can be obtained by using an arrangement similar to that shown in Fig. 6 substituting the transformer for the network. The value of R_T must be high compared with the output impedance of the transformer. Assuming the transformer has a primary: secondary turns ratio of 1:N and that the primary is connected to the E lead of the bridge, the voltage produced across the secondary will be $N \times E$. The secondary current (at balance) is given by $I = NE/R_T$. The conductance reading of the bridge, G_b , is equal to I/E . Therefore, the turns ratio, N , is given by $R_T \times G_b$.

Effectiveness of Transformer Screens

The effectiveness of screens between transformer windings can be determined using the arrangements shown in Fig. 12. The method of measurement when the transformer has a single inter-winding screen is shown in Fig. 12(A) and, in Fig. 12(B), the method of connection when each winding has a separate

screen is shown. With perfect screening there should be no feed through the transformers if connected as shown.

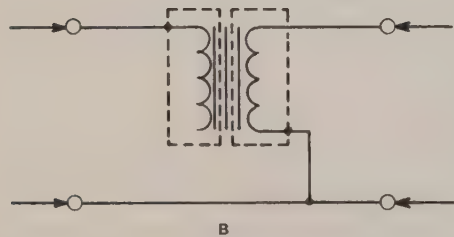
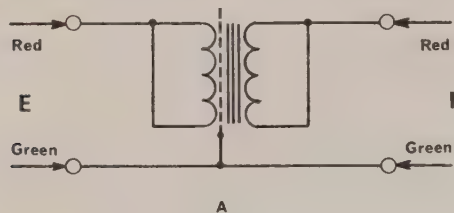


Fig. 12 Transformer Screens

RECIPROCAL TABLES

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Publishers.

Note: Numbers in difference columns to be subtracted,
NOT added.

RECIPROCAL

PROPORTIONAL PARTS OF MEAN DIFFERENCES

	0	1	2	3	4	5	6	7	8	9
1-0	+00000	99010	98039	97087	96154	95238	94340	93458	92593	91743
1-1	90909	90090	89286	88496	87719	86957	86207	85470	84746	84034
1-2	83333	82643	81967	81304	80645	80000	79365	78740	78125	77519
1-3	76923	76336	75758	75188	74627	74074	73529	72993	72464	71942
1-4	71429	70922	70423	69930	69444	68966	68493	68027	67568	67114
1-5	66667	66225	65789	65359	64935	64516	64103	63694	63291	62893
1-6	62500	62112	61728	61350	60976	60606	60241	59880	59524	59172
1-7	58824	58480	58140	57803	57471	57143	56818	56497	56180	55866
1-8	55556	55249	54945	54645	54348	54054	53763	53476	53191	52910
1-9	52632	52356	52083	51813	51546	51282	51020	50761	50505	50251
2-0	50000	49751	49505	49261	49020	48780	48544	48309	48077	47847
2-1	47619	47393	47170	46948	46729	46512	46296	46083	45872	45662
2-2	45455	45249	45045	44843	44643	44444	44248	44053	43860	43668
2-3	43478	43290	43103	42918	42735	42553	42373	42194	42017	41841
2-4	41667	41494	41322	41152	40984	40816	40650	40486	40323	40161
2-5	40000	39841	39683	39526	39370	39216	39063	38911	38760	38610
2-6	38462	38314	38168	38023	37879	37736	37594	37453	37313	37175
2-7	37037	36900	36765	36630	36496	36364	36232	36101	35971	35842
2-8	35714	35587	35461	35336	35211	35088	34965	34843	34722	34602
2-9	34483	34364	34247	34130	34014	33898	33784	33670	33557	33445
3-0	33333	33223	33113	33003	32895	32787	32680	32573	32468	32362
3-1	32258	32154	32051	31949	31847	31746	31646	31546	31447	31348
3-2	31250	31153	31056	30960	30864	30769	30675	30581	30488	30395
3-3	30303	30211	30120	30030	29940	29851	29762	29674	29586	29499
3-4	29412	29326	29240	29155	29070	28986	28902	28818	28736	28653
3-5	28571	28490	28409	28329	28249	28169	28090	28011	27933	27855
3-6	27778	27701	27624	27548	27473	27397	27322	27248	27174	27100
3-7	27027	26954	26882	26810	26738	26667	26596	26525	26455	26385
3-8	26316	26247	26178	26110	26042	25974	25907	25840	25773	25707
3-9	25641	25575	25510	25445	25381	25316	25253	25189	25126	25063
4-0	25000	24938	24876	24814	24752	24691	24631	24570	24510	24450
4-1	24390	24331	24272	24213	24155	24096	24038	23981	23923	23866
4-2	23810	23753	23697	23641	23585	23529	23474	23419	23364	23310
4-3	23256	23202	23148	23095	23041	22989	22936	22883	22831	22779
4-4	22727	22676	22624	22573	22523	22472	22422	22371	22321	22272
4-5	22222	22173	22124	22075	22026	21978	21930	21882	21834	21786
4-6	21739	21692	21645	21598	21552	21505	21459	21413	21368	21322
4-7	21277	21231	21186	21142	21097	21053	21008	20964	20921	20877
4-8	20833	20790	20747	20704	20661	20619	20576	20534	20492	20450
4-9	20408	20367	20325	20284	20243	20202	20161	20121	20080	20040
5-0	20000	19960	19920	19881	19841	19802	19763	19724	19685	19646
5-1	19608	19569	19531	19493	19455	19417	19380	19342	19305	19268
5-2	19231	19194	19157	19120	19084	19048	19011	18975	18939	18904
5-3	18868	18832	18797	18762	18727	18692	18657	18622	18587	18553
5-4	18519	18484	18450	18416	18382	18349	18315	18282	18248	18215
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	1	2	3	4	5	6	7	8	9
1-0									
1-1									
1-2									
1-3									
1-4									
1-5	42	83	125	167	209	250	292	334	375
1-6	37	74	110	147	184	221	258	294	331
1-7	33	65	98	131	164	196	229	262	294
1-8	29	58	88	117	146	175	204	234	263
1-9	26	53	79	105	132	158	184	210	237
2-0	24	48	71	95	119	143	167	190	214
2-1	22	43	65	86	108	130	151	173	194
2-2	20	40	59	79	99	119	139	158	178
2-3	18	36	54	72	91	109	127	145	163
2-4	17	33	50	67	84	100	117	134	150
2-5	15	31	46	62	77	92	108	123	139
2-6	14	29	43	57	72	86	100	114	129
2-7	13	26	40	53	66	79	92	106	119
2-8	12	25	37	49	62	74	86	98	111
2-9	12	23	35	46	58	69	81	92	104
3-0	11	22	32	43	54	65	76	86	97
3-1	10	20	30	40	51	61	71	81	91
3-2	10	19	29	38	48	57	67	76	86
3-3	9	18	27	36	45	53	62	71	80
3-4	8	17	25	34	42	50	59	67	76
3-5	8	16	24	32	40	47	55	63	71
3-6	8	15	23	30	38	45	53	60	68
3-7	7	14	21	28	36	43	50	57	64
3-8	7	14	20	27	34	41	48	54	61
3-9	6	13	19	26	32	38	45	51	58
4-0	6	12	18	24	31	37	43	49	55
4-1	6	12	17	23	29	35	41	46	52
4-2	6	11	17	22	28	33	39	44	50
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5-7	17544	17513	17483	17452	17422	17391	17361	17331	17301	17271
5-8	17241	17212	17182	17153	17123	17094	17065	17036	17007	16978
5-9	16949	16920	16892	16863	16835	16807	16779	16750	16722	16694
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6-2	16129	16103	16077	16051	16026	16000	15974	15949	15924	15898
6-3	15873	15848	15823	15798	15773	15748	15723	15699	15674	15649
6-4	15625	15601	15576	15552	15528	15504	15480	15456	15432	15408
6-5	15385	15361	15337	15314	15291	15267	15244	15221	15198	15175
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7-8	12821	12804	12788	12771	12755	12739	12723	12706	12690	12674
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8-1	2	3	5	6	8	9	11	12	14
8-2	1	3	4	6	7	9	10	12	13
8-3	1	3	4	6	7	9	10	11	13
8-4	1	3	4	6	7	8	10	11	13
8-5	1	3	4	5	7	8	10	11	12
8-6	1	3	4	5	7	8	9	11	12
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8-8	1	3	4	5	6	8	9	10	12
8-9	1	3	4	5	6	8	9	10	11
9-0	1	2	4	5	6	7	9	10	11
9-1	1	2	4	5	6	7	8	10	11
9-2	1	2	4	5	6	7	8	9	11
9-3	1	2	4	5	6	7	8	9	10
9-4	1	2	3	4	6	7	8	9	10
9-5	1	2	3	4	5	7	8	9	10
9-6	1	2	3	4	5	6	8	9	10
9-7	1	2	3	4	5	6	7	8	10
9-8	1	2	3	4	5	6	7	8	9
9-9	1	2	3	4	5	6	7	8	9
	1	2	3	4	5	6	7	8	9

50 kH

1000 =

13

~~1000~~

13

1000 8 n

12

1

10²⁰

013

21
100
0.0025

204K x 1410⁴

80 n
100 n

15-16

159 KHz

33 KHz

C

11.8 nF

800 pF

.230 pF

14.2 nF
at 33 KHz

0.997

11

11

11

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